Damage to Forests from Air Pollution

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Abstract.—Until a few years ago damage to forests from air pollution consisted mainly of localized but very severe cases of mortality and growth loss due to oxides of sulfur or to fluoride associated with ore reduction, with a minor contribution from other sources. In recent years oxidant damage, attributed largely to ozone in Los Angeles smog, is considered partly responsible for destroying ponderosa pine in the mountains east of that city. Oxidant has also been determined as the cause of a long-known needle blight of eastern white pine now called emergence tipburn, and evidence is accumulating that the eastern white pine disease long known as chlorotic dwarf may be due to an abiotic air-borne agent. Mortality and growth loss of this species has also been occurring within a 20-mile radius of certain power plants consuming large quantities of soft coal. When potted ramets (vegetative reproductions) of selected sensitive white pine clones were exposed in an area embracing an industrial complex in east Tennessee, exposure for seven months resulted in uniformly severe damage. Ramets from resistant trees, similarly exposed, suffered no damage. Sensitive ramets kept out of the affected area remained healthy. New and important types of crop damage, including damage to trees, appears to be resulting from air pollution associated with our enormous urban development, with stack gases from new industrial processes, and with greatly increased emissions of stack gases from industrial plants using fossil fuels at rates far beyond consumption only 15 years ago.

THE CLEAN AIR ACT (*10*), passed by the 88th Congress in December 1963, states "that the growth in the amount and complexity of air pollution brought about by urbanization, industrial development, and the increasing use of motor vehicles, has resulted in mounting dangers to the public health and welfare, including injury to agricultural crops and livestock, damage to and the deterioration of property, and hazards to air and ground transportation."

This recognition by Congress of the hazards imposed by the various forms of air pollution to our health and welfare indicate that they can no longer be ignored and no longer be considered local problems with which public agencies need not become involved. Until recent years most of our streams were treated as common sewers into which virtually any liquid waste could be dumped. This situation resulted in a multitude of health, wildlife, and other water use problems that have led to the widespread adoption of strong measures for stream pollution abatement. The public has been slower to recognize the dangers of polluting the atmosphere. So long as acute impacts remained isolated cases, dealt with locally, settled by agreement or litigation, or considered the result of meteorological acts of God, the air has been widely used in the "common sewer" sense with respect to gaseous emissions.

In recent years, however, there has been a slow but steady increase in public awareness of the chronic buildup of pollution levels in many parts of the world. This has been due in part from episodes like the Donora Pennsylvania, fumigation of 1948, the London acute smog of 1952, the smog effects of the Los Angeles area, and from the clear evidence of chronic damage, not only to health but to property, to products of many kinds including paint and rubber, and to agriculture and forestry.

The current literature on the causes and effects of air pollution is enormous and new periodicals on the subject have been appearing at a rapid rate. Good summaries of our air pollution problems were presented by McCabe in 1952, who assembled the contributions to the deliberations of the United States Technical Conference on Air Pollution (*24*), by Stern, who edited an excellent compendium (*35*), by several authorities in the monograph "Air Pollution," released by the World Health Organization in 1961 (*40*), and by the Proceedings of the two National Air Pollution Conferences (*37, 38*). The possible effects of ionizing radiations on plants are not included in the present review.

Information on the many types of air pollution damage to economic plants has been brought together recently by Thomas (*36*), Middleton (*25*), and others (*1, 20*). In the past the principal pollutants have been oxides of sulfur from industrial sources and from London-type smog, and fluorine mainly from ore reduction and the preparation of phosphate fertilizers. Today many additional constituents of polluted air are known to contribute to plant damage, particularly ozone and peroxidized compounds such as peroxyacetyl nitrate (PAN), which are the main elements of Los Angeles-type smog that are toxic to plants and animals. Ozone and PAN result from photochemical reactions between oxides of nitrogen and organic vapors mostly derived from the incomplete combustion of petroleum. In addition to the four principal pollutants already mentioned (sulfur dioxide, fluoride, ozone, and PAN), plant damage has been caused by many other gases including ethylene, chlorine, ammonia, hydrogen chloride, hydrogen sulfide, and others (*36*). While nitrogen oxides are essential to the formation of photochemical smog, and can themselves be toxic to plants (*26*), some consider it questionable that they occur in the atmosphere

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in concentrations high enough to cause injury directly (*36*).

Virtually all of the principal types of agricultural crops have suffered important damage from air pollution. A few examples among nonforest crops might be mentioned (*36*). Alfalfa, cotton, and lettuce have been readily injured by sulfur dioxide at field levels; gladiolus, azalea, and vaccinium are among the most sensitive plants to fluorine; ozone produces weather fleck in tobacco (*13*); ethylene ruins orchid blooms; and a recent report of the University of California states that the photochemical smog from Los Angeles has reduced the production of citrus fruit in the main California citrus area south of that city by 20 to 25 percent in the past 15 years (*4*).

Past Air Pollution Impacts to the Forest

Scheffer and Hedgcock (*32*), in their bulletin on injury to northwestern forest trees by sulfur dioxide from smelters, give a brief literature review of air pollution damage to forests and state that sulfur dioxide discharged from smelters had been the major cause of gas injury to forest trees. The National Research Council of Canada in 1939 released a 447-page report (*29*) on the effects of sulfur dioxide on vegetation, and damage to coniferous trees from smelting was a major feature of this report. Katz (*19*), in Canada, further described damage to coniferous forests from sulfur dioxide, and later Linzon (*21*) measured and documented heavy damage to white pine from sulfur dioxide released in connection with ore smelting in the Sudbury, Ontario, area. Gordon and Gorham (*12*) reported on extensive forest changes attributed to sulfur dioxide around an iron-sintering plant at Wawa, Ontario, where white pine failed to appear on test plots leeward of the plant for a distance of over 30 miles, indicating that this species was the most readily injured of the 30 woody plants recorded. The sensitivity of this tree to the fumes was again pointed up by these authors when white pine showed up for the first time on plots 16 miles leeward from another source, thus making it also the most sensitive of the woody plants recorded in connection with this source.

The Scheffer and Hedgcock study (*32*) cites the losses from mortality, growth reduction, lack of reproduction, and other impacts to many species of forest trees in the upper Columbia River valley south of the Trail, British Columbia, smelter before corrective measures were taken in 1931. Appreciable damage to conifers extended over 40 miles down the river from the smelter. These authors also cite the heavy damage to timber around the Washoe smelter in the vicinity of Anaconda, Montana, revealed by field studies made in 1910 and 1911.

Before corrective measures were instituted, the smelting operations in the Copper Hill, Tennessee, area, early in the century, had laid waste an area of 17,000 acres and damaged another 30,000 acres of timberland (*18*), mostly hardwoods. Much of the area is still virtually bare and eroding severely.

In 1949 an intensive investigation was started of the browning and dying of ponderosa pine within a 50-square-mile area around an aluminum ore reduction plant near Spokane, Washington. In this case the characteristic browning and banding was related to fluoride (*34*). Adams and his coworkers (*2, 3*) have given us much information on the susceptibility of ponderosa pine foliage, particularly when immature, to fluoride, and their work indicates a higher sensitivity of ponderosa pine and lodgepole pine to fluoride than western white pine, Douglas-fir, or Engelmann spruce.

These acute cases of smelter fume injury, while severe, have been fairly local and not numerous. For the most part highly toxic stack emissions from ore reduction have been controlled by various engineering devices and a major bonus of byproduct recovery has followed air pollution reduction measures in many cases. Yet sulfur dioxide and fluoride damage are still problems around a great many sources.

Present Air Pollution Damage to the Forest

Since the rate of growth of forest stands and the vigor and appearance of individual trees are influenced by so many site factors, including soil type, moisture, temperature, drainage, competition, etc., alien impacts not identifiable with known diseases or insects, can go unrecognized unless very severe damage is done. Partly for this reason we have recognized some measure of air pollution damage in the past only where the cause of such damage was obvious. Within recent years, however, injury to and death of trees over large areas, have been attributed to atmospheric insults not related to smelting (*16*). The pollution scientist's term, "atmospheric insult," is used advisedly here, instead of "air pollution," because it is not at all certain that the high oxidant levels that result in some injuries, such as the burning of the tips of eastern white pine needles result, mainly, from man's activities.

It is interesting to note that in four of the cases of forest tree damage recently either proven or considered likely to be caused by atmospheric constituents; namely, thermal power plant stack gas injury to white pine (*7*), ozone injury to white pine (emergence tipburn [*6*]), chlorotic dwarf of white pine (*9*), and chlorotic decline of ponderosa pine (*30*), pathologists spent years eliminating other, more conventional, possible causes before new knowledge and new techniques led the investigators to a consideration of aerological factors.

The loss of individual shade trees is seldom blamed on the atmosphere unless a direct relation to the source of the pollutant is almost self-evident. Cases of killing obviously related to such sources include the blighting of trees in close proximity to automobile exhaust, toxic gas leaks, waste burners, or burning municipal dumps. No one knows the extent of loss of city and highway trees resulting from urban smogs, whether of the reducing (London) type or the oxidizing (Los Angeles) type, but when such data become available they will undoubtedly show that many of our tree species have a low tolerance to urban air. In a general way such tolerance in the East ranges from high, as with the rugged Norway maple and the exotic gingko, to very low

as with the sensitive balsam fir (*8*).

Recent research on the four pine problems already alluded to in connection with atmospheric impacts illustrates that the techniques and fields of knowledge employed in the solution of such problems are quite different from those conventionally used in working with parasites.

Chlorotic Decline of Ponderosa Pine

A condition called chlorotic decline, or X-disease, first noted in the early 1950's has affected ponderosa pine over thousands of acres in the San Bernardino Mountains of California (*30*). Other intermixed conifers of several genera and species have been unaffected. The decline is characterized by reduction in growth; loss of all but the current year's needles; yellowing, mottling, and stunting of needles; and death of trees. Fumigation experiments and air sampling data in the affected area (*28*) suggest that photochemical smog, aggravated by drought, is probably the principal cause of the decline of ponderosa pine in this area, in spite of the elevation (4,000 to 5,000 feet above the valley floor) and a distance of over 50 miles from Los Angeles.

Lodge (*23*) discusses our country's tendency to move from the reducing sulfur dioxide type of urban pollution toward the oxidizing "ozone" pollution as we move from solid to liquid and gas fuels. The particulate matter in smoke tends to reduce photochemical smog through the reduction in light intensity reaching the polluted air. Thus, an increase in oil and gas consumption plus a reduction in smoke can bring us new high levels of oxidant emanating from cities and certain types of industrial activities.

In southern California PAN has apparently been the most destructive smog constituent, while in the East ozone appears to be causing most of the oxidant damage to plants (*31*). With respect to the recent changes in types of pollution, Rodenhiser (*31*) emphasizes that whereas fluoride and sulfur dioxide, which are still major pollutants, are usually traceable to a limited number of large industrial plants, smog comes from "millions" of sources throughout our highly mechanized society.

Reaction of White Pine to Certain Atmospheric Constituents

Recently Berry and Ripperton (*6*) reported on studies indicating that one of the long-known needle blights of white pine, investigated by many pathologists since the turn of the century, is due to atmospheric oxidant, probably ozone. Berry (*5*) first attributed the term "emergence tipburn" (ET) to this trouble, and pointed out that in 1961, when an unusual wave of ET hit the Southeast, an unusual wave of tobacco weather fleck, also an ozone-induced disorder, was reported by North Carolina State College.

When field oxidant concentrations, expressed as ozone, reached 6.5 p.p.h.m. (parts per hundred million) tipburn occurred on susceptible white pine clones. When the ambient air was filtered through an activated carbon filter, thus removing any oxidant, no tipburn occurred. Finally, when susceptible clones were fumigated with ozone at 6.5 p.p.h.m., on the basis of the Mast recorder, tipburn occurred apparently identical in symptoms with the tipburn occurring naturally in the field.

Heggestad and Menser (*14*) produced tobacco weather fleck at concentrations of ozone, as measured by the Mast recorder, and exposure times almost the same as those used by Berry and Ripperton (*6*) in tipburning white pine. Thus ET appears to be the pine analogue of tobacco weather fleck, and an explanation is afforded to a perennial pine problem of previously undetermined cause.

Emergence tipburn is probably one of the commonest white pine troubles that have long been known to us, that occurs in increasing intensity going northward from the southern Appalachian Mountains into New England and Canada, and that is seemingly unrelated to pathogen attack (*22*). A relation to weather, as brought out by Berry (*5*) in connection with ET, by Linzon (*22*) for the same or a similar trouble, and as implied in the term weather fleck of tobacco, is a common denominator in these troubles. The rises in atmospheric ozone, leading to these troubles, whether resulting from natural sources (*36*) or from polluted air (*39*), appear to be related to certain weather patterns.

Another baffling stunting of white pine, called chlorotic dwarf, that occurs widely in the Northeast and Central States is being investigated by Dochinger and Seliskar (*9*). Their recent report, based on grafting experiments and other studies, suggested that the trouble results "from a causal agent that acts directly on the foliage," and no virus, fungus, or other pathogen appeared to be implicated. Regarding the cause, some atmospheric impact has been suggested as a strong possibility.

A third decline of white pine related to one or more atmospheric constituents has occurred within about a 20-mile radius of some soft-coal-burning power plants. Berry and Hepting (*7*) have shown that while fume damage symptoms of the acute sulfur dioxide type, together with elevations in foliar content of sulfate in white pine needles, may occur immediately around a plant of this type, damage of a different kind may extend for 20 or more miles, depending on wind, terrain, and other local conditions The latter, more extensive type of injury, is at least temporarily being called post-emergence chronic tipburn (PECT) to differentiate it from emergence tipburn (ET). While ET, a type of oxidant (probably ozone) injury, starts and ends during the period of shoot elongation and needle growth, PECT may start any time of year, typically showing up first in the winter. PECT is also characterized by a gradual change from a brown tip to a green base, often with mottling or banding in between. The separation of these two troubles from some fungus diseases of white pine is described by Hepting and Berry (*17*).

PECT results in needle blight, a casting of older needles, growth reduction, and often in early death. In the case of all three of the eastern white pine troubles described here, as well as the smog damage to ponderosa pine in the San Bernardino Mountains of California, and fluoride damage to ponderosa pine in Washington (*2*), there is

striking tree-to-tree variability in susceptibility. Normal trees and trees in the last stages of decline may occur side by side, indicating a genetic difference in resistance. These characteristics of resistance or susceptibility are retained in scions after they are grafted on stock trees of the opposite susceptibility tendency. Steps have already been taken to establish a seed orchard of eastern white pine clones resistant to the PECT type of stack gas injury.

When ramets (vegetative reproductions) of a PECT-susceptible clone of white pine were taken from an unpolluted area to an area eight miles from a coal-burning power plant, growth was checked. They lost needles and the remaining needles developed typical PECT symptoms. Ramets of the same clone, in plastic buckets of the same soil, that were left in the unpolluted area remained normal. The trees exposed to pollution for seven months that survived the exposure developed normal foliage within two years after being returned to the unpolluted area (*7*).

PECT of eastern white pine was observed around several thermal power plants in the Appalachian region although the offending gas or gases are still unknown. Although only white pine showed obvious symptoms once away from the immediate environs of the stacks, we have reasons for being concerned with the effects of the increasing output of power plant and industrial stack gases on our forest acreage (*16*).

Trends in Air Pollution as They Affect Trees

An impressive list of crops damaged by photochemical smog from urban pollution can be compiled (*26, 36*), including those in the categories of field, flower, fruit, and vegetable crops, as well as forest trees. Unless measures now being taken by various public and private agencies, and spearheaded on a national basis by the U. S. Public Health Service, can successfully combat this problem in the near future, we can expect increasing damage to orchard, forest, and shade trees. As brought out during the last five years, we will also likely be recognizing certain kinds of damage to trees as caused by air pollution that we have not known the cause of before.

Damage from urban smog can take many forms and extend considerable distances. Parmeter, Bega, and Neff (*30*) point out that the San Bernardino ponderosa pine case involves thousands of acres of land important not only for timber, but for valuable watershed needs, and as a recreational area that attracts more than 4 million visitors each year. Scurfield (*33*) relates how the British National Pinetum had to be moved from Kew, near London, to an area in Kent because of urban air pollution.

Changes in our climate that have been taking place in the past 70 years have been described as probably affecting the incidence of many of our forest diseases (*15*), including both those caused by parasites and by physiogenic influences. Certainly we would expect that climate effects would not only influence the concentration or dissipation of man-made smog and the amount of light energy available for photochemical reactions but also, through subsidence, turbulence, or other meteorologic phenomena, could affect the amount of stratospheric ozone that reaches the troposphere, which is the zone in which we and our plants live. In investigating the possible causes of decline in a number of forest tree species in the Northeast, notably sugar maple, ash, black walnut, oak, and birch, the influence of climatic changes must be considered (*15*). The possible effects of high oxidant levels and other atmospheric impacts are additional influences related to weather that may play a part in these unresolved problems. We must study our trees in relation to their total environment, and polluted air can be an important, and often ignored, part of the environment.

Another upward pollution trend, in addition to urban pollution, is related to thermal power production and it, also, is a source of some concern. Frankenberg (*11*) depicts the growth in large power units of this type. Up to 1954 we had no plants with a boiler capacity of 2 million pounds of steam per hour. By 1962 over 60 percent of our power was generated in such huge new plants. More plants and larger plants, many using low-grade soft coal, mean far greater stack gas emissions. Since the problem of controlling these complex stack gases, which include among other gases sulfur dioxide, fluoride, and oxides of nitrogen, has only been partly solved, we must learn much more than we now know about the impact of the increasing number of such large-capacity, soft-coal-burning industrial units on the surrounding forest vegetation.

Most people today read and hear much about our own and British urban air pollution problems, especially with regard to human health. From our point of view as foresters, it is interesting to note a 1962 Associated Press dispatch from Rome, Italy, that " a special study commission says many of Rome's pine trees are drying up (sic) largely because of gases in the air." It urged city officials to take steps to limit air contamination caused by industrial fumes, smoke from homes and automobile exhaust fumes.

Scurfield (*33*) presents, under the title "Air Pollution and Tree Growth," an impressive compendium, including 258 references, of information on sources of air pollution around the world, and gives examples of damage to different tree species by these pollutants in parts of Germany, England, Russia, the United States, Portugal, Tasmania, South America, South Africa, India, and New Zealand. The more important earlier investigations demonstrating air pollution damage to farm and forest crops was done in Germany as an outgrowth of their industrial expansion starting about a century ago. How individual trees or individual species react to different gases is interesting and important, but it is also important that we determine the expected impact of the many major sources of pollution on our forest and shade tree resources in terms of how much they reduce timber and other forest production, and recreational and civic improvement values. I have tried to show; first, that we have had notable but scattered cases of severe air pollution damage to forests in the past; second, that we

are being subjected to new forms of air pollution, as part of our urban and industrial growth, which have already severely damaged certain tree species over considerable areas in the United States; and third, that as our research facilities, knowledge, and techniques improve, we are finding tree declines due to air pollution that were either erroneously ascribed to other causes or to no cause at all.

Air pollution authorities point out that we have gone beyond strictly urban problems, in the sense of Pittsburgh, St. Louis, or Los Angeles, to regional problems as in southern California, the East Coast, and other industrialized areas. We are finding that we must manage our air as we do our land, water, and forests.

Literature Cited

1. ADAMS, D. F. 1956. The effects of air pollution on plant life. Amer. Med. Assoc. Arch. Indus. Health 14:229-245.
2. ————, C. G. SHAW, and W. D. YERKES, JR. 1956. Relationship of injury indexes and fumigation fluoride levels. Phytopathology 46:587-591.
3. ————, J. W. HENDRIX, and H. G. APPLEGATE. 1957. Relationship among exposure periods, foliar burn, and fluorine content of plants exposed to hydrogen fluoride. Agric. and Food Chem. 5:108-116.
4. ANONYMOUS. 1964. Citrus study under way: smog answer sought. Air in the News 1(9):12.
5. BERRY, C. R. 1961. White pine emergence tipburn, a physiogenic disturbance. U. S. Forest Service, Southeastern Forest Expt. Sta. Paper 130. 8 pp.
6. ————, and L. A. RIPPERTON. 1963. Ozone, a possible cause of white pine emergence tipburn. Phytopathology 53:552-557.
7. ————, and G. H. HEPTING. 1964. Injury to eastern white pine by unidentified atmospheric constituents. Forest Sci. 10:2-13.
8. COLLINGWOOD, G. H., and W. D. BRUSH. 1947. Knowing your trees. The American Forestry Assoc., Washington, D. C.
9. DOCHINGER, L. S., and C. E. SELISKAR. 1963. Susceptibility of eastern white pine to chlorotic dwarf. (Abst.) Phytopathology 53:874.
10. EIGHTY-EIGHTH CONGRESS. 1st Session. 1963. An act to improve, strengthen, and accelerate programs for the prevention and abatement of air pollution. Public Law 88-206, 88 Cong., H. R. 6518. 10 pp. Dec.
11. FRANKENBERG, T. T. 1963. Air pollution from power plants and its control. Combustion 34:28-31.
12. GORDON, A. G., and E. GORHAM. 1963. Ecological aspects of air pollution from an iron-sintering plant at Wawa, Ontario. Canadian Jour. Bot. 41:1063-1078.
13. HEGGESTAD, H. E., and J. T. MIDDLETON. 1959. Ozone in high concentrations as cause of tobacco leaf injury. Science 129:208-209.
14. ————, and H. A. MENSER. 1962. Leaf spot-sensitive tobacco strain Bel W-3, a biological indicator of the air pollutant ozone. (Abst.) Phytopathology 52:735.
15. HEPTING, G. H. 1963. Climate and forest diseases. Ann. Rev. Phytopath. 1:31-50.
16. ————. 1963. [Statement in discussion of agricultural, natural resource, and economic considerations.] *In* Proceedings of the National Conference on Air Pollution of 1962. U. S. Public Health Service. P. 200.
17. ————, and C. R. BERRY. 1961. Differentiating needle blights of white pine in the interpretation of fume damage. Internatl. Jour. Air and Water Pollut. 4:101-105.
18. HURSH, C. R. 1948. Local climate in the Copper Basin of Tennessee as modified by the removal of vegetation. U. S. Dept. Agric. Cir. 774. 38 pp.
19. KATZ, M. 1952. The effect of sulfur dioxide on conifers. *In* U. S. Tech. Conf. on Air Pollution Proc. 1952:84.
20. ————, and V. C. SHORE. 1955. Air pollution damage to vegetation. Jour. Air Pollut. Control Assoc. 5:144.
21. LINZON, S. N. 1958. The influence of smelter fumes on the growth of white pine in the Sudbury region. Ontario Dept. Lands and Forests and Ontario Dept. Mines, Toronto, Ontario. 45 pp.
22. ————. 1960. The development of foliar symptoms and the possible cause and origin of white pine needle blight. Canadian Jour. Bot. 38:153-161.
23. LODGE, J. P. 1957. [Discussion statements.] *In* Proceedings of the Air Pollution Research Planning Seminar of 1962. U. S. Public Health Service. Pp. 32-33.
24. MCCABE, L. C. 1952. Air pollution, U. S. Technical Conference on Air Pollution Proceedings 1950. McGraw-Hill Book Co., New York.
25. MIDDLETON, J. T. 1961. Photochemical air pollution damage to plants. Ann. Rev. Plant Physiol. 12:431-448.
26. ————, and A. O. PAULUS. 1956. The identification and distribution of air pollutants through plant responses. Amer. Med. Assoc. Arch. Indus. Health 14:526-532.
27. ————, D. F. DARLEY and R. F. BREWER. 1957. Damage to vegetation from polluted atmospheres. Amer. Petrol. Inst. Sect. III, Refining, Proc. 8 pp.
28. MILLER, P. ROBERT, J. R. PARMETER, JR., O. C. TAYLOR, and E. A. CARDIFF. 1963. Ozone injury to the foliage of Pinus ponderosa. Phytopathology 53:1072-1076.
29. NATIONAL RESEARCH COUNCIL OF CANADA. 1932. Effect of sulfur dioxide on vegetation. Ottawa. Publ. 815.
30. PARMETER, J. R., JR., R. V. BEGA, and T. NEFF. 1962. A chlorotic decline of ponderosa pine in southern California. U. S. Dept. Agric. Plant Dis. Rptr. 46:269-273.
31. RODENHISER, H. A. 1962. Effects of air pollution on crops and livestock. *In* Proc. of the National Conf. on Air Pollution of 1962. U. S. Public Health Service. Pp. 175-178.
32. SCHEFFER, T. C., and G. G. HEDGCOCK. 1955. Injury to northwestern forest trees by sulfur dioxide from smelters. U. S. Dept. Agric. Tech. Bul. 1117. 49 pp.
33. SCURFIELD, G. 1960. Air pollution and tree growth. Forestry Abst. 21:1-20.
34. SHAW, C. G., G. W. FISHER, D. F. ADAMS, and M. F. ADAMS. 1951. Fluorine injury to ponderosa pine. (Abstr.) Phytopathology 41:943.
35. STERN, A. C., Editor. 1962. Air pollution. 2 volumes. Academic Press, New York.
36. THOMAS, M. D. 1961. Effects of air pollution on plants. *In* Air pollution. World Health Organ. Monog. Series 46. Pp. 233-278.
37. U. S. PUBLIC HEALTH SERVICE. 1958. Proceedings of the National Conference on Air Pollution of 1958. 526 pp.
38. ————. 1963. Proceedings of the National Conference on Air pollution of 1962. 436 pp.
39. WANTA, R. C., W. B. MORELAND, and H. E. HEGGESTAD. 1961. Tropospheric ozone: an air pollution problem arising in the Washington, D. C., metropolitan area. Monthly Weather Rev. 89:289-296.
40. WORLD HEALTH ORGANIZATION. 1961. Air pollution. Monog. Series 46. 442 pp.
41. ZIMMERMAN, P. W. 1952. Effects on plants of impurities associated with air pollution. *In* Air Pollution. U. S. Tech. Conf. on Air Pollution Proc. 1950:127-139.